THE PRINCIPLES OF PARALLEL PROJECTING-LINE DRAWING

ADLER

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THE PRINCIPLES
OF
PARALLEL PROJECTING-LINE DRAWING

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BY
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PART I
OF
THE THEORY OF ENGINEERING DRAWING

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PREFACE

THE present work is the outcome of the author's more extended text entitled the "Theory of Engineering Drawing." In this, the writer saw fit to approach what is now commonly known as Descriptive Geometry, from the viewpoint of drawing. To do this, the principles of projection drawing, which have parallel projecting lines, had to be developed as preliminary to the consideration of Descriptive Geometry proper. The first section of the "Theory of Engineering Drawing" is devoted to this task.

It seemed, to the author, that this first section might be a suitable text for the courses in high schools; for draftsmen who wish to become familiar with the rapid methods of drawing; and for the general reader who desires to acquaint himself with the exceedingly useful subject of drawing. To fill this threefold service, the present edition has been published.

One can easily imagine the importance of drawing in everyday life. Any reference to a material object means a mental image of some form. To transmit this image to others, a drawing is the most practical method. Thus, the subject is not only of importance to the engineer, the builder, or the mechanic, but also to every thinking being, for whom its possession becomes a valuable asset.

The human mind holds a rather limited number of facts. When these are associated, classification and differentiation begin at once, a science of the particular subject is evolved, and the logical processes of reasoning are exercised. Thus, in this work, the author has presented fundamental principles rather than methods. Methods frequently make short cuts to quick applications, but they are detrimental to mental development and act as dead weight on the memory.

Interest in any subject is aroused when the reader feels that he is making progress. The examples at the end of the chapters cover the subject quite completely and in their solution, the test of such progress may be made by each individual student. Thus, he is immediately enabled to apply the principles he has learned and his success in so doing will quicken his interest and lead to a desire for a more advanced knowledge of the subject.

The author acknowledges his indebtedness to his colleague, Ernest J. Streubel, M.A., for his interest in preparing and in reading proofs. The publishers, also, deserve particular commendation for the excellent workmanship manifested throughout these pages.

Polytechnic Institute of Brooklyn,
May, 1912.

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PRINCIPLES
OF
PARALLEL PROJECTING-LINE DRAWING

CHAPTER I

INTRODUCTORY

101. Nature of drawing. Drawing has for its purpose the exact graphic representation of objects in space. The first essential is to have an idea, and then a desire to express it. Ideas may be expressed in **words,** in **pictures,** or in a combination of both **words and pictures.** If words alone are sufficient to express the idea, then **language** becomes the vehicle of its transmission. When the idea relates to some material object, however, a **drawing** alone, without additional information may satisfy its accurate conveyance. Further, some special cases require for their expression a combination of both **language and drawing.**

Consider, for purposes of illustration, a maple block, 2 inches thick, 4 inches wide and 12 inches long. It is easy to conceive this block of wood, and the mere statement, alone, specifies the object more or less completely. On the other hand, the modern newspaper printing press can not be completely described by language alone. Anyone who has ever seen such a press in operation, would soon realize that the intricate mechanism could not be described in words, so as to make it intelligible to another without the use of a drawing. Even if a drawing is employed in this latter case, the desired idea may not be adequately presented, since a circular shaft is drawn in exactly the same way, whether it be made of wood, brass, or steel. Appended notes, in such cases, inform the constructor of the material to use. From the foregoing, it is evident, that drawing cannot become a universal language in engineering, unless the appended descriptions and specifications have the same meaning to all.

102. Science and art of drawing. Drawing is both a **science** and an **art.** The science affects such matters as the proper **arrangement of views** and the manner of their **presentation.** Those who are familiar with the mode of representation used, will obtain the idea the maker desired to express. It is a science, because the facts can be **assimilated, classified,** and **presented** in a more or less **logical** order. In this book, the science of drawing will engage most of the attention; only such of the artistic side is included as adds to the ease of the interpretation of the drawing.

The **art** lies in the skilful application of the scientific principles involved to a definite purpose. It embraces such topics as the **thickness** or **weight** of lines, whether the **outline** alone is to be drawn, or whether the object is to be **colored** and **shaded** so as to give it the same appearance that it has in nature.

103. Magnitude of objects. Objects visible to the eye are, of necessity, **solids,** and therefore require the **three principal dimensions** to indicate their magnitude—**length, breadth,** and **thickness.** If the observer places himself in the proper position while viewing an object before him, the object impresses itself on him as a whole, and a mental estimate is made from the one position of the observer as to its form and magnitude. Naturally, the first task will be to represent an object in a single view, showing it in three dimensions, as a solid.

104. Commercial application of drawing. It must be remembered that the function of drawing is graphically to present an idea on a flat surface—like a sheet of paper for instance—so as to take the place of the object in space. The reader's imagination supplies such deficiency as is caused by the absence of the actual object. It is, therefore, necessary to study the various underlying principles of drawing, and, then, apply them as daily experience dictates to be the most direct and accurate way of their presentation. In any case, only one interpretation of a drawing should be possible, and if there is a possibility of ambiguity arising, then a note should be made on the drawing calling attention to the desired interpretation.

QUESTIONS ON CHAPTER I

1. In what ways may ideas be transmitted to others?
2. What topics are embraced in the science of drawing?
3. What topics are included in the art of drawing?
4. How many principal dimensions are required to express the magnitude of objects? What are they?
5. What is the function of drawing?
6. Is the reader's imagination called upon when interpreting a drawing? Why?

CHAPTER II

OBLIQUE PROJECTION

201. Nature of oblique projection. Suppose it is desired to draw a box, 6″ wide, 12″ long and 4″ high, made of wood $\frac{1}{2}$″ thick. Fig. 1 shows this drawn in oblique projection. The method of making the drawing will first be shown and then the theory on which it is based will be developed. A rectangle **abcd**, 4″×6″, is laid out, the 6″ side being horizontal and the 4″ side being vertical. From three corners of the rectangle, lines **ae**, **bf**, and **cg** are drawn, making, in this case, an angle of 30° with the horizontal. The length 12″ is laid off on an inclined line, as **cg**. The extreme limiting lines of the box are then fixed by the addition of two lines **ef** (horizontal) and **fg** (vertical). The thickness of the wood is represented, and the dimensions showing that it is $\frac{1}{2}$″ thick indicate the direction in which they are laid off. The reason for the presence of such other additional lines, is that they show the actual construction.

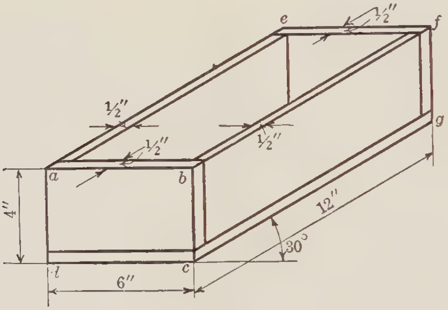

Fig. 1.

The sloping lines in Fig. 1 could be drawn at any angle other than 30°. In Fig. 2, the same box is drawn with a 60° inclination. It will be seen, in this latter case, that the inside bottom of the box is also shown prominently. It is customary in the application of this type of drawing, to use either 30°, 45° or 60° for the slope, as these lines can be easily drawn with the standard triangles used in the drafting room.

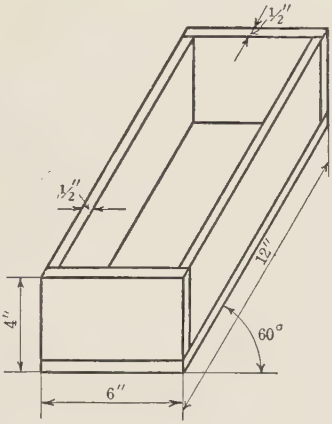

FIG. 2.

202. Oblique projection of lines parallel to the plane of projection. In developing the theory, let **XX** and **YY**, Fig. 3, be two planes at right angles to each other. Also, let **ABCD** be a thin rectangular plate, the plane of which is parallel to the plane **XX**. Suppose the eye is looking in the direction **Aa**, **inclined*** to the plane **XX**. Where this line of sight from the point **A** on the object appears to **pierce** or **impinge** on the plane **XX**, locate the point **a**. From the point **B**, assume that the eye is again directed

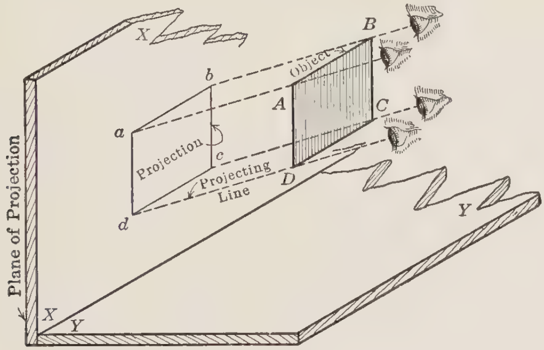

FIG. 3.

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* The ray must not be perpendicular, as this makes it an orthographic projection. The ray cannot be parallel to the plane of projection, because it will never meet it, and, hence, cannot result in a projection.

toward the plane **XX**, in a line that is parallel to **Aa**; this second piercing point for the point **B** in space will appear at **b**. Similarly, from the points **C** and **D** on the object, the piercing points on the plane will be **c** and **d**, **Cc** and **Dd** being parallel to **Aa**.

On the plane **XX**, join the points **abcd**. To an observer, the figure **abcd** will give the same mental impression as will the object **ABCD**. In other words, **abcd** is a **drawing** of the thin plate **ABCD**. **ABCD** is the **object** in space; **abcd** is the corresponding **oblique projection** of **ABCD**. The plane **XX** is the **plane of projection; Aa, Bb, Cc**, and **Dd**, are the **projecting lines,** making any angle with the plane of projection other than at right angles or parallel thereto. The plane **YY** serves the purpose of throwing the plane **XX** into stronger relief and has nothing to do with the projection.

It will be observed that the figure whose corners are the points **ABCDabcd** is an oblique rectangular prism, the opposite faces of which are parallel because the edges have been made parallel by construction. From the geometry, all parallel plane sections of the prism are equal, hence **abcd** is equal to **ABCD**, because the plane of the object **ABCD** was originally assumed parallel to **XX**, and the projection **abcd** lies in the plane **XX**. As a corollary, the distance of the object from the plane of projection does not influence the size of the projection, so long as the plane of the object is continually parallel to the plane of projection.

Indeed, any line, whether straight or curved, when parallel to the plane of projection has its projection equal to the line itself. This is so because the curved line may be considered as made up of an infinite number of very short straight lines.

203. Oblique projection considered as a shadow. Another way of looking at the projection shown in Fig. 3 is to assume that light comes in parallel lines, oblique to the plane of projection. If the object is interposed in these parallel rays, then **abcd** is the shadow of **ABCD** in space, and thus presents an entirely different standpoint from which to consider the nature of a projection. Both give identical results, and the latter is here introduced merely to reenforce the understanding of the nature of the operation.

204. Oblique projection of lines perpendicular to the plane of projection. Let **XX**, Fig. 4, be a transparent plane surface, seen edgewise, and **ab**, an arrow perpendicular to **XX**, the end **a** of the arrow lying in the plane. Suppose the eye is located at **r** so that the ray of light **rb** makes an angle of 45° with the plane **XX**. If all rays of light from points on **ab** are parallel to **rb**, they will pierce the plane **XX** in a series of points, and **ac**, then, will become the projection of **ab** on the plane **XX**. To an observer standing in the proper position, looking along lines parallel to **rb**, **ac** will give the same mental impression as the actual arrow **ab** in space; and, therefore, **ac** is the projection of **ab** on the plane **XX**. The extremities of the line **ab** are hence projected as two distinct points **a** and **c**. Any intermediate point, as **d**, will be projected as **e** on the projection **ac**.

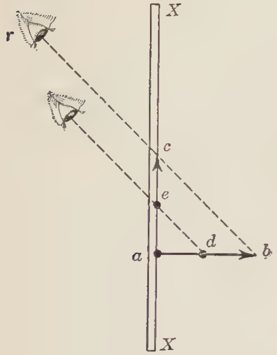

Fig. 4.

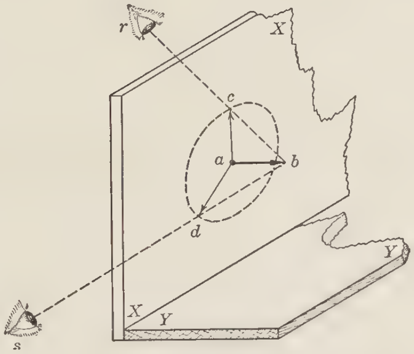

Fig. 5.

From the geometry, it may be noticed that **ac** is equal to **ab**, because **cab** is a right angled triangle, and the angle **acb** equals the angle **cba**, due to the adoption of the 45° ray. Also, any limited portion of a line, perpendicular to the plane of projection, is projected as a line equal to it in length. The triangle **cab** may be rotated about **ab** as an axis, so that **c** describes a circle in the plane **XX** and thus **ac** will always remain equal to **ab**. This means that the rotation merely corresponds to a new position of the eye, the inclination of the ray always remaining 45° with the plane **XX**.

The foregoing method of representing 45° rays is again shown as an oblique projection in Fig. 5. Two positions of the ray are indicated as **rb** and **sb**; the corresponding projections are **ac** and **ad**. Hence, in constructing oblique projections, the lines that are parallel to the plane of projection are drawn with their true relation to each other. The lines that are perpendicular to the plane of projection are drawn as an inclined line of a length equal to the line itself and making any angle with the horizontal, at pleasure. Here, again, the plane **YY** is added. The line of intersection of **XX** and **YY** is perpendicular to the plane of the paper, and is shown as a sloping line, because the two planes themselves are pictured in oblique projection.*

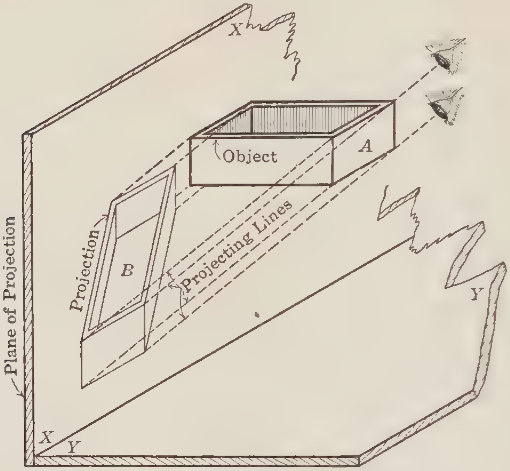

FIG. 6.

205. Oblique projection of the combination of parallel and perpendicular lines to the plane of projection. Fig. 6 shows a box and its projection, pictorially **indicating** all the **mental steps** required in the construction of an oblique projection. The object (a box) **A** is shown as an oblique projection;

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* Compare this with Figs. 1 and 2. The front face of the box is shown as it actually appears, because it is parallel to the plane of projection (or paper). The length of the box is perpendicular to the plane of the paper and is projected as a sloping line.

its projection **B** on the plane of projection appears very much distorted. This distortion of the projection is due to its being an oblique projection, initially, which is then again shown in oblique projection. From what precedes, the reader should find no difficulty in tracing out the construction. Attention may again be called to the fact that the extremities of the lines perpendicular to the plane of projection are projected as two distinct points.

206. Oblique projection of circles.* When the plane of a circle is parallel to the plane of projection, it is drawn with a compass in the ordinary way, because the projection is equal to the circle itself (202). When the plane of the circle is perpendicular to the plane of projection, however, it is shown as an ellipse. Both cases will be illustrated by Fig. 7, which shows a cube in oblique projection. In the face **abcd**, the circle is shown as such, because the plane of the circle is parallel to the plane of projection, which, in this case, is the plane of the paper. It will be noticed that the circle in **abcd** is tangent at points midway between the extremities of the lines. If similar points of tangency are laid off in the faces **aefb** and **fbcg** and a smooth curve be drawn through these points, the result will be an ellipse; this ellipse is, therefore, the oblique projection of a circle, whose plane is perpendicular to the plane of projection. The additional lines in Fig. 7 show how four additional points may be located on the required ellipse.

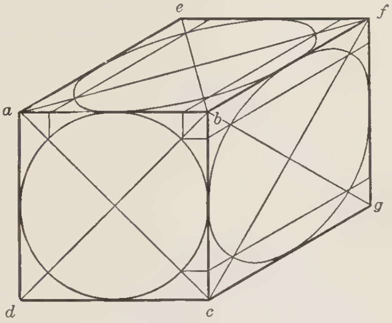

FIG. 7.

It may be shown that a circle is projected as an ellipse in all cases except when its plane is parallel to the plane of projection, or, when its plane is chosen parallel to the projecting lines. In the latter case, it is a line of a length equal to the diameter of the circle. The reason for this will become evident later in the subject. (It is of insufficient import at present to dwell on it at length.)

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* When projecting circles in perpendicular planes, the 30° slope offers an advantage because the ellipse is easily approximated. See Art. 405.

207. Oblique projection of inclined lines and angles. At times, lines must be drawn that are neither parallel nor perpendicular to the plane of projection. A reference to Fig. 8 will show how this is done. It is desired to locate a hole in a cube whose edge measures 12″. The hole is to be placed in the side **bfgc**, 8″ back from the point **c** and then 4″ up to the point **h**. To bring this about, lay off **ck**=8″ and **kh** (vertically) =4″ and, then **h** is the required point. Also, **hkc** is the oblique projection of a right angled triangle, whose plane is perpendicular to the plane of projection. Suppose, further, it is desired to locate the point **m** on the face **abfe**, 7″ to the right of the point **a** and 5″ back. The dimensions show how this is done. Again, **man** is the oblique projection of a right angled triangle, whose legs are 5″ and 7″. This method of laying off points is virtually a method of **offsets.*** The point **m** is offset a distance of 5″ from **ab**; likewise **h** is offset 4″ from **cg**. If it be required to lay off the diagonal of a cube, it is accomplished by making three offsets from a given point. For instance, consider the diagonal **ce**. If **c** is the starting point, draw **cg** perpendicular to the plane (shown as an inclined line), then **fg**, vertically upward, and finally **fe**, horizontally to the left; therefore, **ce** is the diagonal of the cube, if **eg**=**gf**=**fe**.†

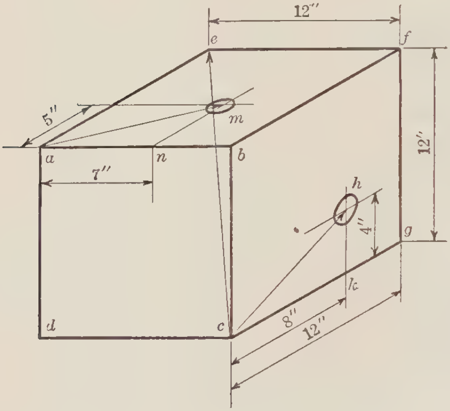

FIG. 8.

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[*] This method is of importance in that branch of mathematics known as Vector Analysis. Vectors are best drawn in space by means of oblique projection.

[†] If two given lines are parallel in space, their oblique projections are parallel under any conditions. The projecting lines from the extremities of

A word may be said in reference to round holes appearing in the oblique faces of a cube. As has been shown, circles are here represented as ellipses (206), but if it were desired to cut an elliptical hole at either **h** or **m**, then their projections would **not** give a clear idea of the fact. Such cases, when they occur, must be covered by a note to that effect; an arrow from the note pointing to the hole would then indicate, unmistakably, that the hole is to be drilled (for a round hole), otherwise its shape should be called for in any way that is definite. It seems, therefore, that oblique projection cannot fulfill the needs of commercial drawing in every respect; and, indeed, this is true. Other methods also have certain advantages and will be treated subsequently.‡

208. Representation of visible and invisible lines. While viewing an object, the observer finds that some lines on the object are **visible.** These lines are drawn in **full** on the projection. There are, however, other lines, **invisible** from the point of view chosen and these, when added, are shown **dotted.** Fig. 9 shows all the visible and invisible lines on a hollow circular cylinder. Dimensions are appended and the cylinder shaded so that no question should arise as to its identity. It can be observed that the drawing is clear in so far as it shows that the hole goes entirely through the cylinder. Were the dotted lines omitted, one could not tell whether the hole went entirely through, or only part way through. Hence, dotted lines may add to the clearness of a drawing; in such cases they should be added. At times, however, their addition may lead to confusion; and, then, only the

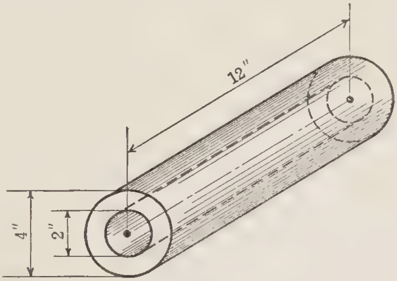

Fig. 9.

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the given lines determine planes that cut the plane of projection in lines which are the projections of the given lines. The projecting planes from the given lines are parallel, and, hence, their projections are parallel, since it is the case of two parallel planes cut by a third plane.

‡ The student will obtain many suggestions by copying such simple illustrations as Figs. 1, 2, 7, 8 and 9.

more important dotted lines added, and such others, considered unnecessary, should be omitted. Practice varies in this latter respect and the judgment of the draftsman comes into play at this point; ability to interpret the drawing rapidly and accurately is the point at issue.

209. Drawings to scale. Objects of considerable size cannot be conveniently represented in their full size. The shape is maintained, however, by reducing the length of each a definite proportion of its original length, or, in other words, by drawing **to scale.** Thus, if the drawing is one-half the size of the object, the **scale** is $6''=1$ ft. and is so indicated on the drawing by a note to that effect. The scales in common use are $12''=1$ ft. or full size; $6''=1$ ft. or half-size; $3''=1$ ft. or quarter size; $1\frac{1}{2}''$; $1''$ $\frac{3}{4}''$; $\frac{1}{2}''$; $\frac{3}{8}''$; $\frac{1}{4}''$; $\frac{3}{16}''$; $\frac{1}{8}''$; $\frac{1}{16}''$; $\frac{1}{32}''$; etc.$=1$ ft. The smaller sizes are used for very large work and vice versa. In railway work, scales like $100'=1$ inch, or $10000'=1$ inch are common. In watch mechanism, scales like $48''=1$ ft. or " four times actual size " or even larger are used, since, otherwise, the drawings would be too small for the efficient use of the workman. Irrespective of the scale used, the **actual** dimensions are put on the drawing and the scale is indicated on the drawing by a note to that effect.

If some dimensions are not laid out to the scale adopted, the drawing may create a wrong impression on the reader and this should be avoided if possible. When changes in dimensions occur after the completion of a drawing and it is impracticable to make the change, the dimension may be underlined and marked conveniently near it **N T S,** meaning " not to scale."

210. Examples of oblique projection. Fig. 10 shows a square block with a hole in its centre. The dimension lines indicate the size and the method of making the drawing when the planes of the circles are chosen parallel to the plane of the paper (plane of projection). The circle in the visible face is drawn with a compass to the desired scale. The circle in the invisible face (invisible from the point of view chosen) is drawn to the same radius, but, its centre is laid off on an inclined line, a distance back of the visible circle, equal to the thickness of the block. The circle in the front face is evidently not in the same plane as that in the distant face. The line joining their centres is thus perpendicular to the plane of projection, and is, hence, laid off as an inclined line.

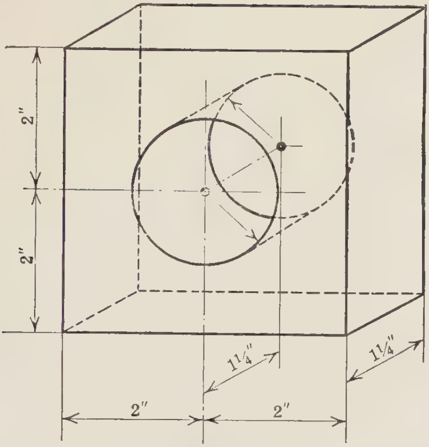

Fig. 10.

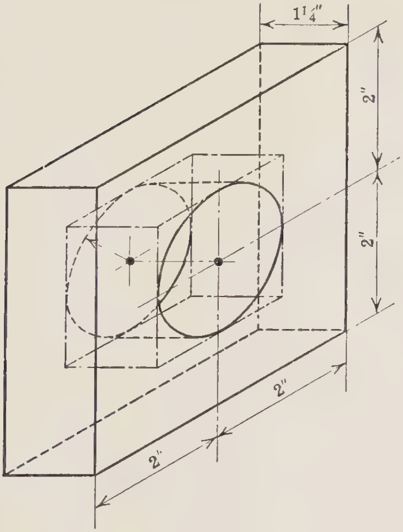

Fig. 11.

When the plane of the circles is made perpendicular to the plane of projection, the circles are projected as ellipses. Fig. 11 shows how the block of Fig. 10 is drawn when such is the case. It is to be observed, that the bounding square is to be drawn first and then the ellipse (projection of the circle) is inscribed. When the circles in both faces are to be shown, the bounding

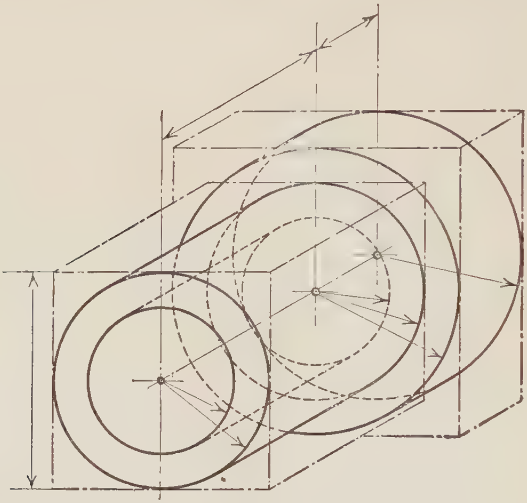

FIG. 12.

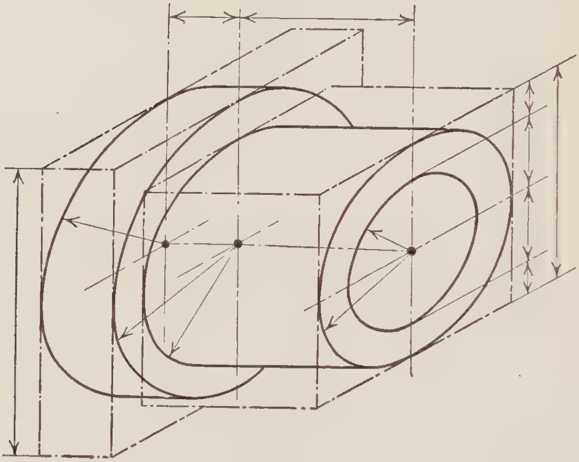

FIG. 13.

square must be replaced by a bounding rectangular prism. This rectangular prism is easily laid out and the ellipses are inserted in the proper faces. The method of using bounding figures of simple shape is of considerable importance when applying the foregoing principles to oblique projection.

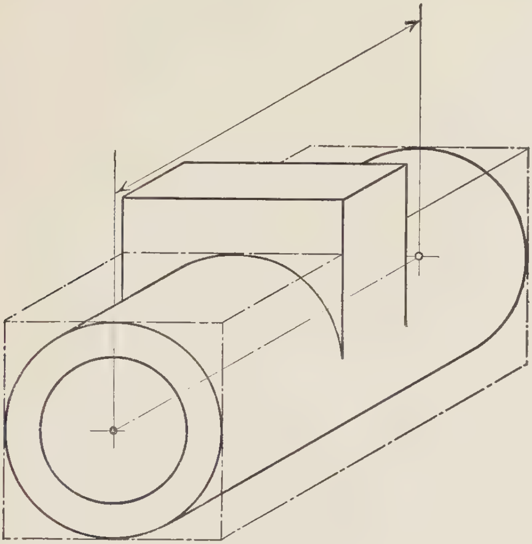

Fig. 14.

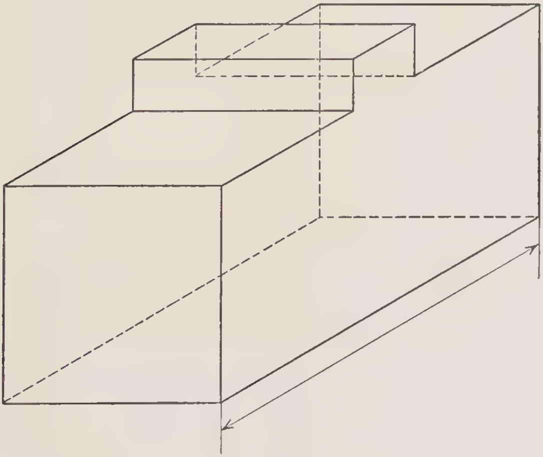

Fig. 15.

Fig. 12 is another illustration of an object, differing from Figs. 10 and 11 in so far as the hole does not go entirely through from face to face. The centres for the different circles are found on the axis. The distances between the centres, measured on the inclined line, is equal to the distances between the planes of the corresponding circles. Since the circles are drawn as such, the planes must, therefore, be parallel to the plane of projection. The axis of the hole is perpendicular to the plane of projection, and, hence, is projected as an inclined line.

The object in Fig. 12 is also shown with the planes of the circles perpendicular to the plane of projection in Fig. 13. Every step of the construction is indicated in the figure and the series of bounding prisms about the cylinders is also shown.

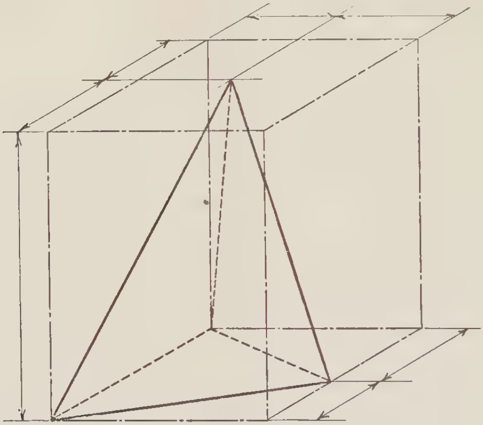

Fig. 16.

A somewhat different example, showing the necessity of bounding figures, is given in Fig. 14. The bounding figure, shown in Fig. 15, is laid out as given and it becomes a simple matter to insert the object subsequently. It should be noted how the rectangular projection becomes tangent to the cylinder and that the only way to be certain of the accuracy of the drawing, is to use these bounding figures and make mental record of the relative location of the lines that make up the drawing.

If objects are to be drawn whose lines are inclined to each other, the principles so far developed offer simple methods for their presentation. Fig. 16 shows a tetrahedron with a bounding rectangular prism. The apex is located on the top face and its position is determined from the geometric principles imposed. Solids, as represented in the text-books on geometry, are drawn in this way. Some confusion may be avoided by observing that angles are only preserved in their true relation in the planes parallel to the plane of projection (207).

The concluding example of this series is given in Fig. 17. It is known as a bell-crank and has circles shown in two planes at right angles to each other. The example furnishes the clue to constructing any object, however complicated it may be. Base lines **ab** and **bc** are first laid out to the required dimensions and to the desired scale. In this example, the base lines are chosen parallel to the plane of projection, and hence are projected as a right angle, true to dimensions. The thickness of the two lower cylinders is laid off as an inclined line from each side of the base line and the circles are then drawn. The upper circles (shown as ellipses) may need some mention. A bounding rectangular prism is first drawn, half of which is laid off on each side of the base line (true in this case but it may vary in others).

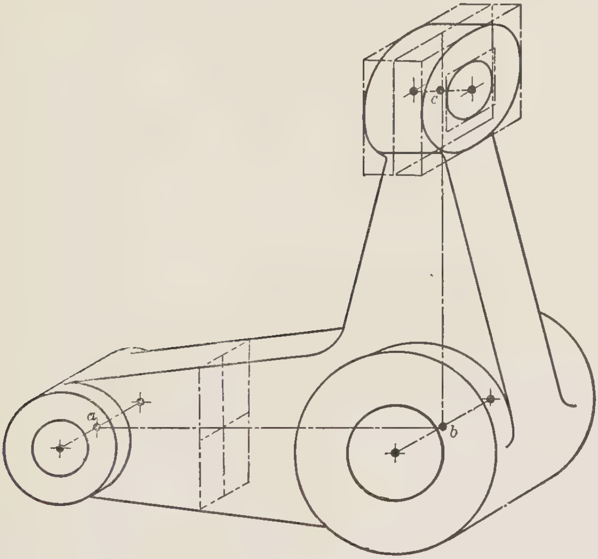

Fig. 17.

The circles and inclined lines are filled in after the guiding details are correctly located. This drawing may present some difficulty at first, but a trial at its reproduction will reveal no new principles, only an extreme application.

On completion of the drawing, the bounding figure may be removed if its usefulness is at an end. When inclined lines appear frequently on the drawing, the bounding figures can be made to serve as dimension lines, and so help in the interpretation. The draftsman must determine what is best in each case, remembering, always, that the drawing must be clear not only to himself, but to others who may have occasion to read it.

211. Distortion of oblique projection. A view of a completed machine suffers considerable distortion when drawn in oblique projection because the eye cannot be placed in any one position, whereby it can view the drawing in the manner the projection was made.* To overcome this difficulty to some extent and to avoid bringing the distortion forcibly to the attention of the observer, the projecting lines can be so chosen that the perpendicular to the plane of projection is projected as a shorter line than the perpendicular itself. Fig. 18 shows this in construction. **XX** is a vertical transparent plate, similar to that shown in Fig. 4. The ray **rb** makes an angle with **XX** greater than 45°, and, by inspection, it is seen that the projection of **ab** on **XX** is **ac**, which is shorter than **ab**, the perpendicular.

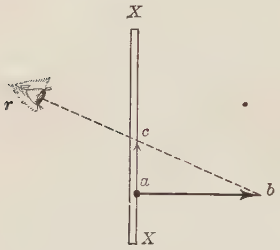

Fig. 18.

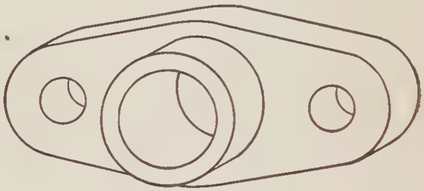

Fig. 19.

The application of the foregoing reduces simply to this: All lines and curves parallel to the plane of projection are shown exactly the same as in oblique projection with 45° ray inclination. The lines that are perpendicular to the plane of projection are reduced to $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{8}$, etc. of their original length and reduced or increased to the scale adopted in making the drawing. This mode of representation* is suitable for making catalogue cuts and the like. It gives a sense of depth without very noticeable distortion, due to two causes: the impossible location of the eye while viewing the drawing, and, the knowledge of the apparent decrease in size of objects as they recede from the eye. A single illustration is shown in Fig. 19.

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* This condition is satisfied in Perspective Projections.

212. Commercial application of oblique projection. Oblique projection is useful in so far as it presents the three dimensions in a single view. When curves are a part of the outline of the object, it is desirable to make the plane of the curve parallel to the plane of projection, thereby making the projection equal to the actual curve and also economizing time in making the drawing. Sometimes it is not possible to carry this out completely. Fig. 17, already quoted, shows an example of this kind. It is quite natural to make the drawing as shown, because the planes of most of the circles are parallel to the plane of projection, leaving, thereby, only one end of the bell-crank to be projected with ellipses.

Oblique projections, in general, are perhaps the simplest types of drawings that can be made, if the objects are of comparatively simple shape. They carry with them the further advantage that even the uninitiated are able to read them, when the objects are not unusually intricate. The making of oblique projections is simple, but, at the same time, they call on the imagination to some extent for their interpretation. This is largely due to the fact that the eye changes its position for each point projected, and that no one position of the eye will properly place the observer with respect to the object.

The application of oblique projection to the making of drawings for solid geometry is already known to the student and the resulting clarity has been noticed. Other types of projections have certain advantages which will be considered in due order.

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* This type of projection has been called Pseudo Perspective by Dr. MacCord in his Descriptive Geometry.

The convenience of oblique projection to the laying out of piping diagrams is worthy of mention. Steam and water pipes, plumbing, etc., when laid out this way, result in an exceedingly readable drawing.

QUESTIONS ON CHAPTER II

1. What is an oblique projection?
2. What is a plane of projection?
3. What is a projecting line?
4. Prove that when a rectangle is parallel to the plane of projection the projection of the rectangle is equal to the rectangle itself.
5. Does the distance of the object from the plane have any influence on the size of the projection? Why?
6. Prove that any line, whether straight or curved, is projected in its true form when it is parallel to the plane of projection.
7. Show under what conditions a projection may be considered as a shadow.
8. Prove that when a line is perpendicular to the plane of projection, it is projected as a line of equal length, when the projecting rays make an angle of 45° with the plane of projection. Use a diagram.
9. Prove that any limited portion of a line is projected as a line of equal length, when the line is perpendicular to the plane of projection and the projecting lines make an angle of 45° with the plane of projection.
10. Show how a perpendicular may be projected as a longer or a shorter line, if the angle of the projecting lines differs from 45°.
11. Why can not the projecting lines be selected parallel to the plane of projection?
12. Show that when a line is parallel to the plane of projection, it is projected as a line of equal length, irrespective of the angle of the projecting lines, provided the projecting lines are inclined to the plane of projection.
13. Why may the slope of the projection of a line perpendicular to the plane of projection be drawn at any angle?
14. Prove that when two lines are parallel to each other and also to the plane of projection, their projections are parallel.
15. Prove that when two lines are perpendicular to the plane of projection, their projections are parallel to each other.
16. Draw two rectangular planes at right angles to each other so that the edges of the planes are parallel or perpendicular to the plane of the paper (or projection).
17. Draw a cube in oblique projection and show which lines are assumed parallel to the plane of projection and which lines are perpendicular to the plane of projection.
18. Draw a cube in oblique projection and show how the circles are inserted in each of the visible faces.

19. Show how angles are laid off on the face of a cube in oblique projection.
20. Under what conditions is the angular relation between lines preserved?
21. Draw a line that is neither parallel nor perpendicular to the plane of projection. (Use the cube, in projection, as a bounding figure.)
22. Prove that any two lines in space are projected as parallels when they themselves are parallel.
23. Under what conditions will the oblique projection of a line be a point?
24. How are visible and invisible lines represented on a drawing?
25. What is meant by drawing to scale?
26. Why is it desirable to have all parts of the same object drawn to true scale?

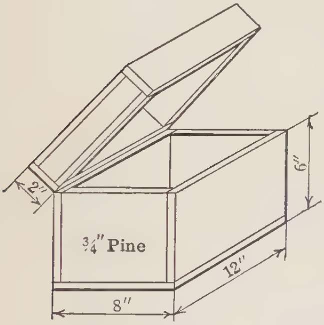

FIG. 2*A*.

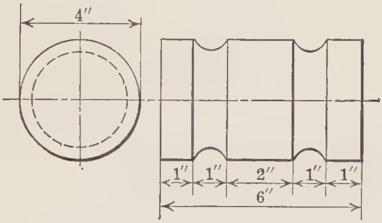

FIG. 2*B*.

27. What considerations govern the choice of the scale to be used on a drawing?
28. Show how the distortion of an oblique projection may be reduced by changing the angle of the projecting lines.
29. Why is it impossible to locate the eye in one position and view the projection in the manner in which it was made?
30. Draw a rectangular box with a hinged cover, in oblique projection, and show the cover partly raised.
31. Draw a lever, having a round hole on one end so as to fit over a shaft. Have the plane of the circles parallel to the plane of projection.
32. Draw an oblong block, 2″×3″×6″ long, in oblique projection, having a 1″ hole in its centre, 4″ deep.
33. Draw a cylindrical shaft, 6″ in diameter and 18″ long, in oblique projection, having a rectangular hole, 2″×3″×5″ deep, from each end. Lay out to a scale of 3″=1 ft. and affix all dimensions.

34. Draw a triangular prism, in oblique projection, showing how the bounding figure is used.
35. Draw a hexagonal prism, in oblique projection, and show all the invisible (dotted) lines on it.
36. Draw a hexagonal pyramid in oblique projection.
37. Make a material list for the box shown in Fig. 2*A*.
38. Draw the circular cylinder, 4″ diameter and 6″ long, shown in Fig. 2*B*. On the surface of this cylinder, two semi-circular grooves are cut, as shown by the dimensions. Make two drawings in oblique projection, one showing the plane of the circles parallel to the plane of projection and the other, with the plane of the circles perpendicular to the plane of projection.

Note.—For additional drawing exercises see examples in Chapters III and IV.

CHAPTER III

ORTHOGRAPHIC PROJECTION

301. Nature of orthographic projection. Take, for example, a box $6'' \times 12'' \times 4''$ high, made of wood, $\frac{1}{2}''$ thick. This box is shown orthographically in Fig. 20, and requires two distinct views to illustrate it properly. The upper view, or **elevation,** shows the side of the box whose outside dimensions are $4'' \times 12''$, while the thickness of the wood is indicated by the dotted lines. The lower view is called the **plan,** and is obtained by looking down into the inside of the box. It is thus to be remembered that the **two views** are due to **two** distinct **directions of vision** on the part of the observer.

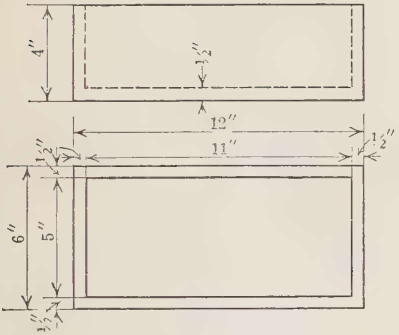

Fig. 20.

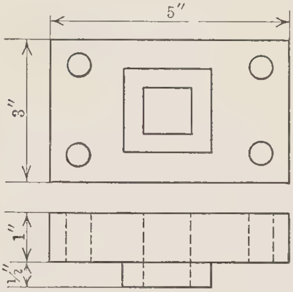

Fig. 21.

As another example of this mode of representation, consider the object shown in Fig. 21. It is here a rectangular plate, $5'' \times 3''$ and $1''$ thick, with a square hole in its centre. The metal around the square hole projects $\frac{1}{2}''$ above the surface of the plate. In addition, there are four bolt holes which enable the part to be secured to a machine with bolts. As before, two views are shown with the necessary dimensions for construction.

302. Theory of orthographic projection. Let Fig. 22 represent an oblique projection of two plane surfaces **HH** and **VV**, at right angles to each other. For mechanical operations to be performed later, it is assumed that they are hinged at their intersection so that both planes may be made to lie as one flat surface, instead of two separate surfaces at right angles to each other. The plane **HH**, shown horizontally, is the **horizontal plane of projection**; that shown vertically, is the **vertical plane of projection**; their intersection is called the **ground line.** The two planes, taken together, are known as the **principal planes** of projection. The object is the 4″×6″×12″ box chosen as an illustration in Fig. 20. The drawing on the horizontal plane is the **horizontal projection;** while that on the vertical plane is the **vertical projection.**

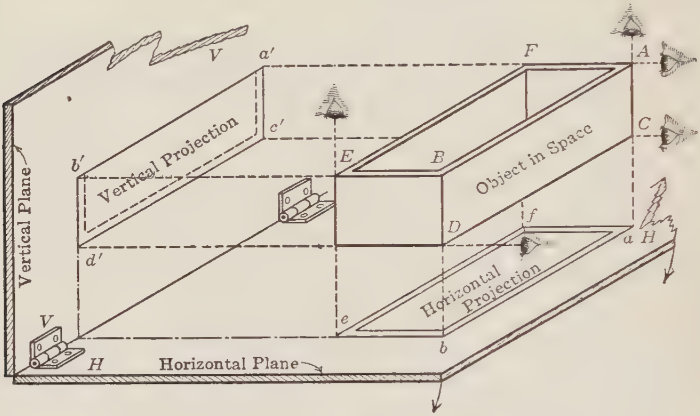

FIG. 22.

The method of constructing the projection consists of dropping perpendiculars from the object upon the planes of projection. Thus, in other words, the **projecting lines** are **perpendicular** to the plane of projection. To illustrate: The box is so located in space that the bottom of it is parallel to the horizontal plane (Fig. 22) and the 4″×12″ side is parallel to the vertical plane. From the points **A**, **B**, **C**, and **D**, perpendiculars are drawn to the vertical plane and the points, where these perpendiculars **pierce** or **impinge** on the plane, are marked **a′**, **b′**, **c′**, and **d′**, to correspond with the similarly lettered points on the object. By joining these points with straight lines, to correspond with the lines on the object, the vertical projection is completed, when the dotted lines showing the inside of the box are added.

Turning to the projection on the horizontal plane, it is seen that **A**, **B**, **E**, and **F** are the corners of the box in space, and that perpendiculars from these points to the horizontal plane determine **a**, **b**, **e**, and **f** as the horizontal projection. It is assumed that the observer is looking down on the horizontal plane and therefore sees the inside of the box; these lines are hence shown in full, although the projecting perpendiculars are omitted so as to avoid too many lines in the construction.

303. Revolution of the horizontal plane. It is manifestly impracticable to carry two planes at right angles to each other, each containing one projection of an object. A more convenient way is to represent both projections on a single plane surface, so that such drawings can be represented on a flat sheet of paper. The evident expedient, in this case, is to **revolve** the horizontal plane about the ground line as an axis, until it coincides with the plane of the vertical plane. The conventional direction of rotation is shown by the arrow in Fig. 22, and to accomplish this coincidence, a 90° revolution is required. In passing, it may be well to note that it makes no difference whether the horizontal plane is revolved as suggested, or whether the vertical plane is revolved in the opposite direction into coincidence with the horizontal plane. Both accomplish the same purpose, and hence either method will answer the requirements.

304. Position of the eye. The perpendicular projecting lines drawn to the planes of projection correspond with a line of sight that coincides with these perpendiculars. Each point found on the projection, corresponds to a new position of the eye. All projecting lines to one plane are then evidently parallel because they are all perpendicular to the same plane. As two projections are required, two general directions of vision are necessary. That for the horizontal projection requires the eye above that plane, continually directed perpendicularly against it; thus the eye is continually shifting in position, although the direction of vision is fixed. Also, the vertical projection requires that the eye be directed perpendicularly against it, but in this case, the line of sight is perpendicular to that required for the horizontal projection.

305. Relation of size of object to size of projection. The object is projected on the planes by lines perpendicular to it. If the plane of the object is parallel to the plane of projection, then the projection is equal to the object in magnitude. This is true because the projecting lines form a right prism and all the parallel plane sections are the same (compare with 202). Fig. 23 gives the construction of the projection in Fig. 21. **ABCDa′b′c′d′** is such a right prism because the plane of the object is parallel to the plane of projection and the projecting lines are perpendicular to the plane of projection.

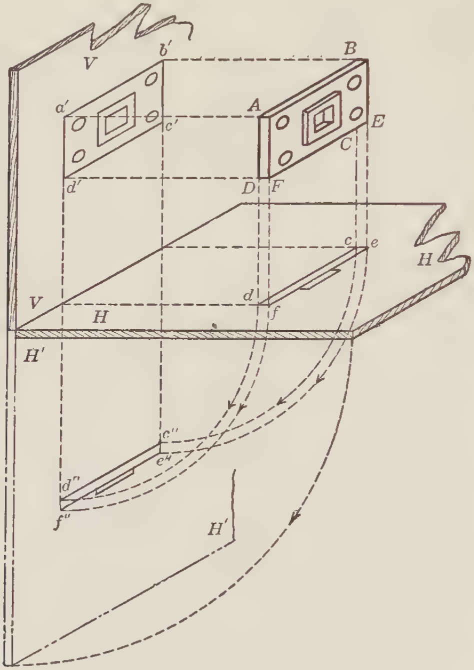

Fig. 23.

306. Location of object with respect to the planes of projection. For purposes of drawing, the location of the object to the planes of projection is absolutely immaterial. In fact, the draftsman intuitively makes the projections and puts corresponding projections as close as is necessary to economize room on the sheet.

307. Location of projections with respect to each other. In Figs. 20 and 21, the vertical projection is placed directly above the horizontal projection. Reference to Fig. 23 will show why such is the case. When the horizontal plane is revolved into coincidence with the vertical plane, the point **d** will describe the arc of a circle **dd″** * which is a quadrant; **d″** is the ultimate position of the point **d** after revolution, and must be on a line **d′d″** which is perpendicular to the original position of the horizontal plane. So, too, every point of the horizontal projection is located directly under the corresponding point in the vertical projection, and the scheme for finding its position is identical to that for finding **d** at **d″**.

308. Dimensions on a projection. When the principal planes of the object are turned so that they are parallel to the planes of projection, then the edges will, in the main, be perpendicular to the planes of projection. In Fig. 23, **DF** is one edge of the object and it is perpendicular to the vertical plane of projection **VV**. The projection of this line is **d′**, because the projecting perpendicular from any point on **DF** will coincide with **DF** itself. The result of this is that the thickness of the object is not shown when the length and breadth are shown, or, in other words, only two of the three principal dimensions are shown in a single view. Thus, another view is required to show the thickness. If **DC** be considered a length, and **DF** a thickness, the horizontal projection shows both as **dc** and **df**. The vertical projection does not show the thickness **DF** as it is perpendicular to the vertical plane of projection. Hence, in reading orthographic projections, both views must be **interpreted simultaneously,** as each shows but **two** of the **three principal dimensions** and only one of the three is common to both projections.

309. Comparison between oblique and orthographic projections. It is of interest here to show wherein the orthographic projection differs from the oblique. When the plane of the object is parallel to the plane of projection, the projection on that plane is equal to the object, whether it is projected orthographically or obliquely. When a line is perpendicular to the plane of projection its extremities have **two** distinct **projections** in **oblique** projection, but only **one** in **orthographic** projection. This latter statement means simply that if the projecting lines instead of being oblique to the plane of projection, gradually assume the perpendicular position, the two projections of the extremities of any line approach each other until they coincide when the projecting lines are perpendicular. Therefore, in orthographic projection, the third dimension vanishes and a new view must be made in addition to the other, in order to represent a solid.

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* d′ is read d prime; d″ is read d second; d‴ is read d third; and so on.

310. Orthographic projection considered a shadow. The horizontal and the vertical projections may be considered as shadows on their respective planes. The source of light must be such that the rays emanate in parallel lines, and are directed perpendicularly to the planes of projection. Evidently, the two views are due to two distinct positions of the source of light, one whose rays are perpendicular to the horizontal plane while casting the horizontal shadow, and the other, whose rays are perpendicular to the vertical plane while casting the vertical shadow.

311. Profile plane. Let **A**, in Fig. 24, be the horizontal projection and **B**, the vertical projection of an object. The two views are identical, and to one unfamiliar with the object, they are indefinite, as it is impossible to tell whether they are projections of a cylinder or of a prism. By the addition of either view **C** or **D**, it is at once apparent that the object in question is a circular cylinder, a hole running part way through it and with one end square.

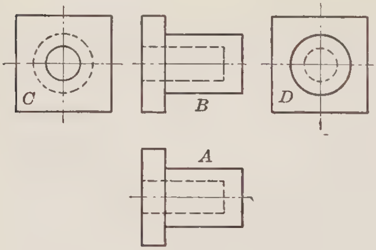

Fig. 24.

Fig. 25 shows how this profile is made. As customary, the horizontal and vertical planes are present and the projection on these planes should now require no further mention. A

profile plane (or end plane as it may be called) is shown on the far side of the object and is a plane that is perpendicular to both the horizontal and vertical planes (like the two adjacent walls and the floor of a room meeting in one corner). A series of perpendiculars is dropped from the object upon this profile plane, as shown by the dotted lines, and thus the side view is determined.

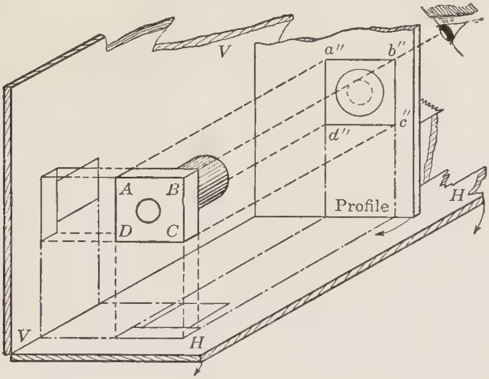

Fig. 25.

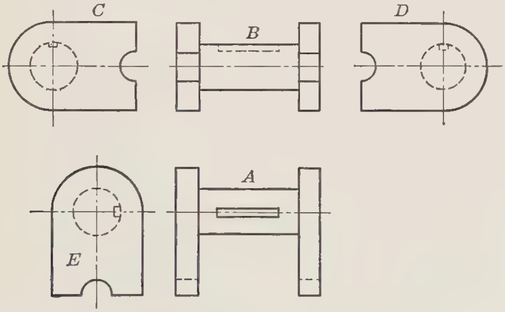

Fig. 26.

312. Location of profiles. If the profile view is to show the object as seen from the left side, it is put on the left side of the drawing, and vice versa. Fig. 24 shows two profile views located in accordance with this direction. Either views **B** and **C**

or **B** and **D** completely represent the object. In this case, although this is not always so, the horizontal projection is not essential.

Fig. 26 gives still another illustration of an object that is not as symmetrical as that immediately preceding. The illustration is chosen to show exactly how the profile planes are revolved into the vertical plane, if the vertical plane be assumed as the plane of the paper. **A** is the horizontal and **B** the vertical projection of the object. **C** and **D** are two profiles, drawn against the vertical projection, whereas **E** is a profile drawn against the horizontal projection. Fig. 27 shows a plan view of the vertical and two profile planes. In reading this drawing, the horizontal plane is the plane of the paper, while the vertical plane is seen on edge and is shown as **VV**, as are also the left and right profile planes indicated respectively as **LL** and **RR**.

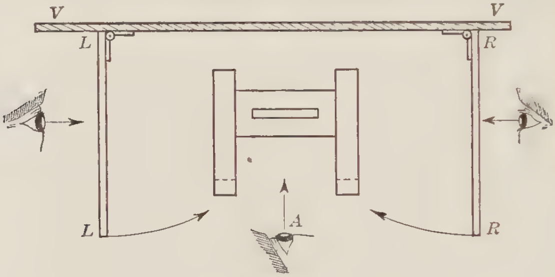

Fig. 27.

In making the projection on the horizontal plane, the object is above the plane and the projecting perpendiculars are dropped from points on the object to the horizontal plane, which in this case is the plane of the paper. The construction of the vertical projection (that on **VV**) is indicated by the arrow **A**. The arrangement here shown corresponds to the views **A** and **B** in Fig. 26.

When making the profile projections, the planes are assumed as transparent, and are located between the object and the observer. As the observer traces the outline on these profile planes, point by point, each ray being perpendicular to the plane, the resultant picture so drawn becomes the required projection. If, then, the planes **LL** and **RR** be revolved in the direction of the arrows until they coincide with the vertical plane, and then the vertical plane be further revolved into the plane of the paper, the final result will be that of Fig. 26 with view **E** omitted.

View **E** is a profile drawn against the horizontal projection and is shown on the left because it is the projection on the profile plane **LL**. It has been revolved into the horizontal plane, by revolving the profile plane so that the upper part of the plane moves toward the object into coincidence with the horizontal plane.

Fig. 26 has more views than are necessary to illustrate the object completely. In practice, all would not be drawn, their presence here is necessary only to show the method.

313. Section plane. The addition of dotted lines to the drawing of complicated objects is unsatisfactory at times on account of the resultant confusion of lines. This difficulty can be overcome by cutting the object by planes, known as **section planes.** The solid material when so exposed is **sectioned** or **cross-hatched** by drawing a series of equidistant lines over the exposed area. A convenient mnemonic in this connection is to assume that the cut is made by a saw and that the resultant tooth marks represent the section lines. Fig. 28 shows what is known as a stuffing box on a steam engine. This is a special case where but one projection is shown in **section** and one profile. The left-hand view might have been shown as an outside view, but the interior lines would then have been shown dotted. As it is, the object is cut by the plane **ab** and this half portion is shown to the left, sectioned of course, because the cut is not actual.

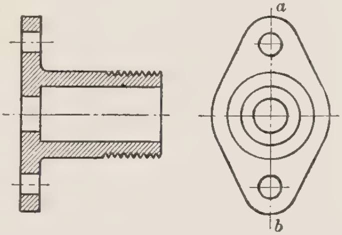

Fig. 28.

Another example is seen in Fig. 29, where a fly-wheel is represented in much the same way as in the illustration in Fig. 28. It differs somewhat from that immediately preceding in so far as the two views do not have the theoretical relation. Were the wheel actually cut by the plane **ab** then the arms (spokes) shown in the profile would have to be sectioned. As shown, however, the arms appear in full as though the section plane passed through the wheel a short distance ahead of the spokes. The convention is introduced for a double purpose: In the first place it avoids peculiar projections as that for the plane **cd** for instance, where the spokes would be foreshortened because they incline to the plane of projection. In the second place, the sectioning of the spokes is the conventional method of showing a band wheel,* that is, a wheel with a solid web, or, in other words, without spokes. Hence, it appears that although it may not seem like a rational method of drawing, still the attending advantages are such as make it a general custom. The mechanics who use the drawings understand this, and therefore it becomes common practice.

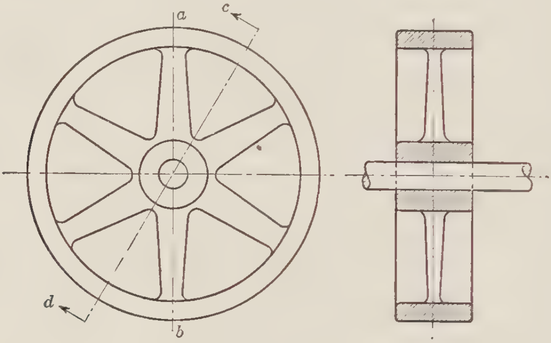

Fig. 29.

Many more examples could be added, but they would be too complicated to be of illustrative value. It may be said, that, in some cases, six or more sections may be made to illustrate the object completely. They are located anywhere on the drawing and properly indicated, similar to **cd** in Fig. 29. It may also be mentioned, that in cases like that of the fly-wheel, the shaft is not cut by the section plane but is shown in full as it appears in Fig. 29.

314. Supplementary plane. Fig. 30 shows a **Y** fitting used in pipe work for conveying steam, water, etc., and consists of a hollow cylindrical shell terminating in two flanges, one at each end. From this shell there emerges another shell (in this case, smaller in diameter), also terminating in a flange. **A** is the **Y** fitting proper; **B** is the end view of one flange, showing the bolt holes for fastening to a mating flange on the next piece of pipe, not shown. The view **B** shows only the one flange that is represented by a circle, because the profile plane is chosen so as to be parallel to that flange. If the flange at **C** be projected on this same profile plane, it would appear as an ellipse, and, as such, could not be drawn with the same facility as a circle. Here, then, is an opportunity to locate another plane, called a **supplementary plane,** parallel to the flange at **C**. The projection of **C** on this supplementary plane will be a circle and is therefore readily drawn with a compass.

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* Fig. 43 is an example of a band wheel.

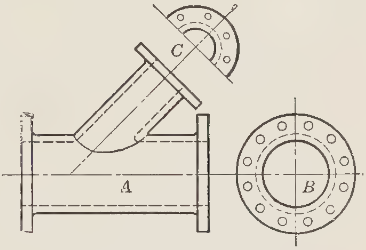

Fig. 30.

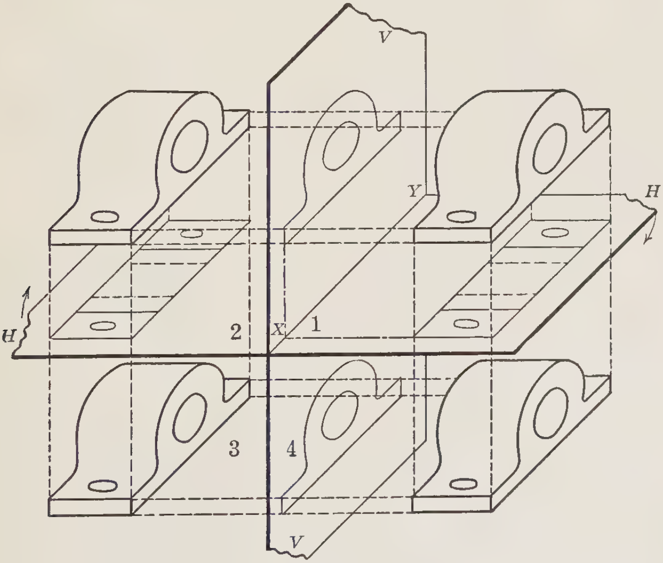

Fig. 31.

Only one-half of the actual circle may be shown if desired so as to save time, space, or both time and space. The bolt holes are shown in the supplementary view at **C** just the same as in view **B**. Either plane may be considered supplementary to the other; on neither plane is the entire projection made, because the object is of so simple a character. To avoid the possibility of any error arising, the supplementary projection is, if it is at all possible, located near the part to be illustrated. If, for any reason, this view cannot be so located, a note indicating the proper position of the view is added to the drawing.

315. Angles of projection. Up to the present point, no attention has been devoted to the angles in which the projections were made. As will soon appear, the examples so far chosen were all in the first angle. Fig. 31 shows two planes **HH** and **VV**, intersecting at right angles to each other. The planes form **four** dihedral angles, numbered consecutively in a counter-clockwise manner as indicated. The same object is shown in all four angles, as are also the projections on the planes of projection, thus making four distinct projections.

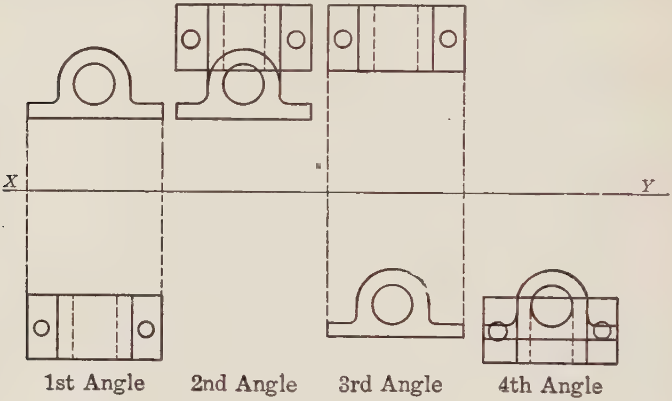

Fig. 32.

316. Location of observer in constructing projections. The eye is always located above the horizontal plane in making any horizontal projection. That is, for objects in the **first** and **second** angles, the **object** is **between** the **plane** and the **observer;** for objects in the **third** and **fourth** angles the **plane** is between the **object** and the **observer.** While constructing the vertical projections the eye is always located in front of the vertical plane. That is, for objects in the **first** or **fourth** angles, the **object** is **between** the **plane** and the **observer;** but in the **second** and **third** angles, the **plane** is **between** the **object** and the **observer.** This latter means simply that the observer stands to the right of this vertical plane **VV** and views it so that the line of sight is always perpendicular to the plane of projection.

317. Application of angles of projection to drawing. If the horizontal plane be revolved about the ground line **XY** as indicated by the arrows, until it coincides with the vertical plane of projection, it will be seen that that portion of the horizontal plane in front of the vertical plane will fall below the ground line, whereas that portion of the horizontal plane behind the vertical plane will rise above the ground line.

Supposing that in each position of the object in all four angles, the projections were made by dropping the customary perpendiculars to the plane of projection, and in addition, that the revolution of the horizontal plane is accomplished, then the resultant state of affairs will be as shown in Fig. 32. For purposes of illustration, the ground line **XY** is drawn although it is never used in the actual drawing of objects.* Also, the object has been purposely so located with respect to the planes that the second and fourth angle projections overlap. Manifestly the second and fourth angles cannot be used in drawing if we wish to be technically correct. It may be possible so to locate the object in the second and fourth angles, by simply changing the distance from one plane or the other, that the two projections do not conflict, but a little study will show that the case falls either under first or third angle projection, depending upon whether the vertical projection is above the horizontal projection, or, below it.

It will be seen that in the first angle of projection, the plan is below and the elevation is above; whereas in the third angle of projection the condition is reversed, that is, the plan is above and the elevation is below. Strictly speaking, the profile, section and supplementary planes, have nothing to do with the angle of projection, but it is quite possible to take a single projection with its profile, and locate it so that it corresponds to a third angle projection. Thus, there appears a certain looseness in the application of these principles. In general, **the third angle of projection is used more than any other** * as the larger number of mechanics are familiar with the reading of drawings in this angle. Fig. 33 shows the same object in the first and third angles of projection. A profile, or end view, is also attached to each, thus making a complete, though simple illustration.

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* When lines, points, and planes are to be represented orthographically, the ground line becomes a necessary adjunct.

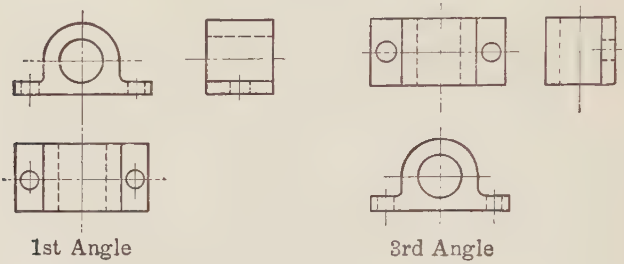

Fig. 33.

318. Commercial application of orthographic projection. Orthographic projection is by far the most important method of making drawings for engineering purposes. Other types of drawing have certain advantages, but, in general, they are limited to showing simple objects, made up principally of straight lines.

Some experience is required in reading orthographic projections because two or more views must be interpreted simultaneously. This experience is readily acquired by practice, both in making drawings and in reading the drawings of others.

To compensate for the more difficult interpretation of this type of drawing, there are inherent advantages, which permit the representation of any object, if it has some well defined shape. By the aid of sections, profiles, and supplementary planes, any side of a regular body can be illustrated at will, and further than this, the curves are shown with such peculiarity as characterizes them. Bodies, such as a lump of coal, or a spade full of earth, are considered shapeless, and are never used in engineering construction. Even these can be represented orthographically, however, although it is quite difficult to draw on the imagination in such cases.

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* The third angle of projection should be used in preference to the first because the profile, section, and supplementary planes conform to third angle projection.

QUESTIONS ON CHAPTER III

1. What are the principal planes of projection? Name them.
2. What is the ground line?
3. What angles do the orthographic projecting lines make with the plane of projection?

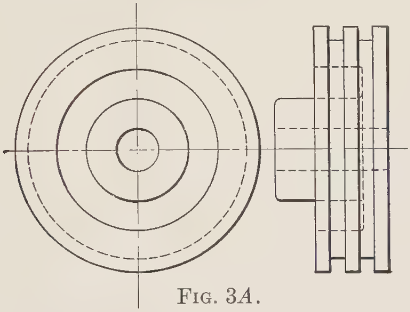

FIG. 3A.

4. What is the horizontal projection?
5. What is the vertical projection?
6. Why is the horizontal plane revolved 90° after making the projections?

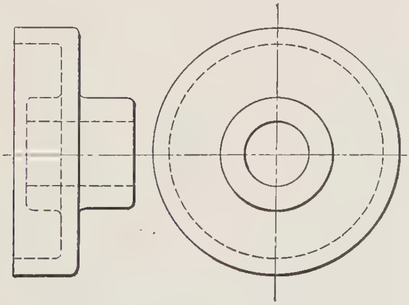

FIG. 3B.

7. Could the vertical plane be revolved instead of the horizontal plane?
8. Make a sketch of the planes of projection and show by arrow how the revolution of the planes is accomplished.
9. How is the eye of the observer directed in making an orthographic projection?

10. What is the general angular relation between the projecting lines to the horizontal plane and the vertical plane of projection?
11. Why is the projection of the same size as the object?
12. Why is the ground line omitted in making orthographic projections?
13. Why are corresponding projections located directly over each other? Show by diagram.
14. Why does an orthographic projection show only two of the three principal dimensions of the object?

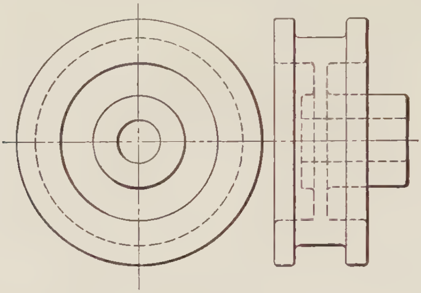

Fig. 3C.

15. Why must the two views of an orthographic projection be interpreted simultaneously?
16. Compare the direction of the projecting lines of oblique projection with those of orthographic projection.
17. Show how the source of light must be located in order that the shadow should correspond to a true projection.

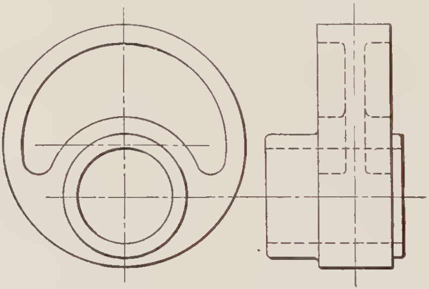

Fig. 3D.

18. To cast the horizontal and vertical shadows, is it necessary to have two distinct positions for the source of light?
19. What is a profile plane?
20. How is the profile plane located with respect to the principal planes of projection?
21. How is the profile plane revolved into the plane of the drawing? Show by diagram.

22. How are the profiles located with respect to the main projection? Show by some simple sketch.
23. What is a section plane?
24. When is a section plane desirable?
25. How is the section constructed?

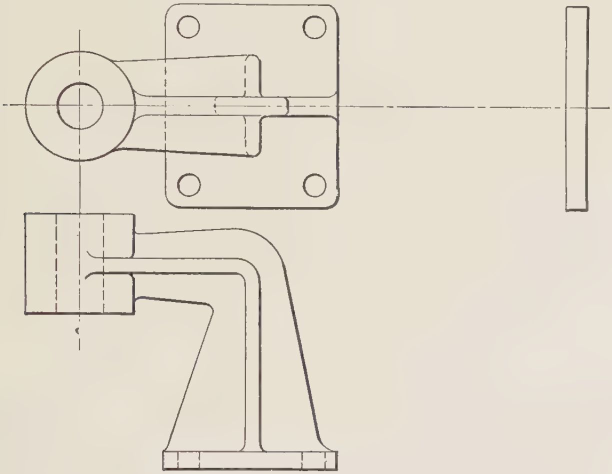

FIG. 3*E*.

26. How is the section located with respect to the main projection?
27. Show a simple case where only one projection and one section completely determine an object.

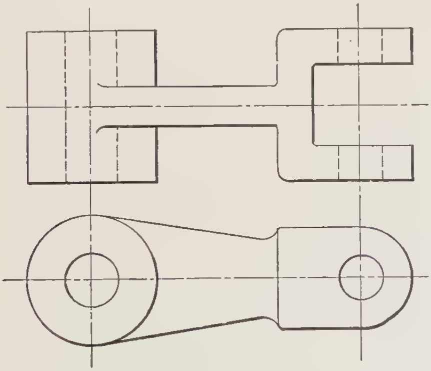

FIG. 3*F*.

28. What is a supplementary plane?
29. When is it desirable to use a supplementary plane?
30. How is the supplementary projection located with respect to the main projection?

31. Show why the profile plane is a special case of the supplementary plane.
32. Make a diagram showing the four angles of projection and show how they are numbered.

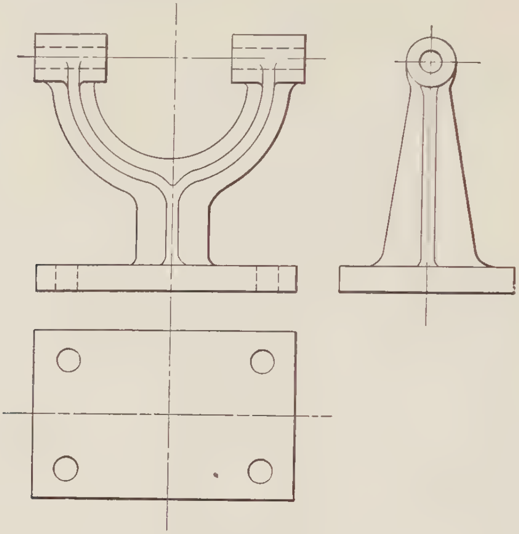

FIG. 3G.

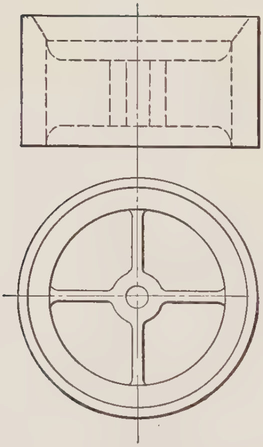

FIG. 3H.

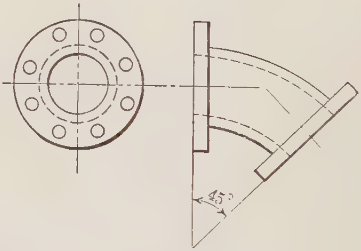

FIG. 3I.

33. How is the revolution of the planes accomplished so as to bring them into coincidence?
34. How is the observer located in making first angle projections?

35. How is the observer located in making second angle projections?
36. How is the observer located in making third angle projections?
37. How is the observer located in making fourth angle projections?
38. Why are only the first and third angles of projection used in drawing?
39. How does the third angle differ from the first angle projection? Show by sketch.
40. Why is the third angle to be preferred?

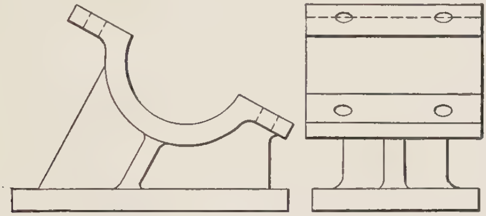

Fig. 3*J*.

41. Why is it more difficult to read orthographic projections than oblique projections?
42. What distinct advantages has orthographic projection over oblique projection?

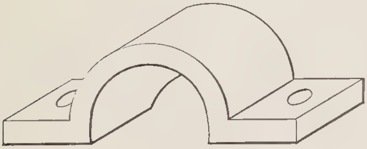

Fig. 3*K*.

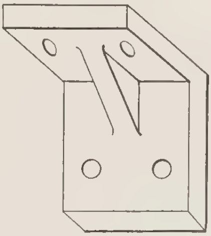

Fig. 3*L*.

43. Make a complete working drawing of 3–A and show one view in section. Assume suitable dimensions.

Note: A working drawing is a drawing, completely dimensioned, with all necessary views for construction purposes.

44. Make a complete working drawing of 3–B and show one view in section. Assume suitable dimensions.
45. Make a complete working drawing of 3–C and show one view in section. Assume suitable dimensions.
46. Make a complete working drawing of 3–D and show one view in section. Assume suitable dimensions.

47. Make a complete working drawing of 3–E and show the profile on the left, to the top view. Assume suitable dimensions.
48. Make a complete working drawing of 3–F and show the profile on the left, to the top view. Assume suitable dimensions.
49. Make a complete working drawing of 3–G and show the lower view as a first angle projection. Assume suitable dimensions.
50. Rearrange 3–G and show three views in third angle projection.
51. Make a section of 3–H through the web and observe that the web is not sectioned. Assume suitable dimensions.
52. Make a supplementary view of the 45° ell shown in 3–I. Assume suitable dimensions.
53. Make a supplementary view of 3–J. Assume suitable dimensions.
54. Make three views of 3–K in third angle projection. Assume suitable dimensions.
55. Make three views of 3–L in third angle projection. Assume suitable dimensions.

CHAPTER IV

AXONOMETRIC PROJECTION

401. Nature of isometric projections. Consider three lines intersecting at a point and make the angles between each pair of lines equal to 120°; the three angles will then total 360° which is the total angle about a point. If on one of these lines, or lines parallel thereto, lengths are laid off, on the other line, or lines parallel thereto, breadths are laid off; and on the remaining line, or lines parallel thereto, thicknesses are laid off, it seems quite reasonable that a method may be devised whereby the three principal dimensions can be plotted so as to represent objects in a single view. This method when carried out to completion results in an **isometric projection.**

Let, in Fig. 34, **OA**, **OB**, and **OC** be the three lines, drawn as directed, so that the angles between them are 120°. Suppose it is desired to draw a box 4″×6″×12″, made of wood ½″ thick. Lay off 12″ on **OB** (to any convenient scale), 6″ on **OA** and 4″ on **OC**. From **A**, draw a line **AD** parallel to **OB** and **AE** parallel to **OC**; also, from **C** draw **CE**, parallel to **OA** and **CF**, parallel to **OB**. The thickness of the wood is to be added and the direction in which this is laid off is indicated by the direction of the corresponding dimension line. In the drawing, the line **OC** was purposely chosen vertical so that **OA** and **OB** may be readily drawn with a 60° triangle. The other lines, added to indicate the construction, are self-explanatory.

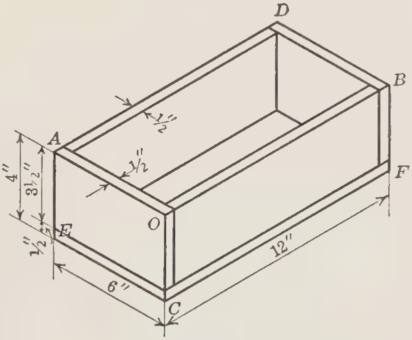

Fig. 34.

This, then, is an isometric projection, and, as may be noted, is a rapid method of representing objects in a single view. Comparison may be made with Figs. 1 and 20, which show the same box in oblique and orthographic projection, respectively.

402. Theory of isometric projection. Let Fig. 35, represent a cube shown on the left side of a transparent plane **VV**. If the observer, located on the right, projects this cube orthographically (projecting lines perpendicular to the plane) on the plane **VV**, and at the same time has the cube turned so that each of the three visible faces is projected equally on the plane, the resultant projection is an **isometric projection** of the cube on the plane **VV**.

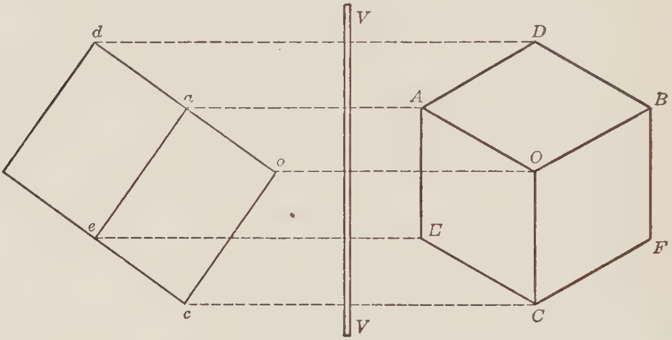

Fig. 35

The illustration on the right of Fig. 35 shows how this cube appears when orthographically projected. **OA**, **OB**, and **OC** are called the **isometric axes.** As each face of the cube is initially equal to the other faces, and as each edge is also equal, then, with equal inclination of the three faces, their projections are equal. Hence, the three angles are each equal to 120° and the three isometric axes are equal in length. To use these axes for drawing purposes merely requires that all dimensions of one kind (lengths, for instance) be laid off on any one line, or lines parallel thereto, and that this process be observed for the three principal dimensions.

Isometric projection, is, therefore, a special case of orthographic projection; because, in its conception, the principal planes of the object are inclined to the plane of projection. As solids are thereby represented in a single view, only one projection is necessary.

403. Isometric projection and isometric drawing. When a line is inclined to the plane of projection, the orthographic projection of the line is shorter than that of the line itself, for, if the degree of inclination continue, the line will eventually become perpendicular to the plane and will then be projected as a point. Thus, in Fig. 35, **OA**, **OB**, and **OC** are drawn shorter than the actual edges of the cube, and the projection on the right is a true isometric projection. In the application of this mode of projection, however, it is easier to lay off the actual distance (or any proportion of it) rather than this foreshortened distance. If commercial scales are used in laying out the drawing instead of the true isometric projections, then it is called an **Isometric Drawing.**

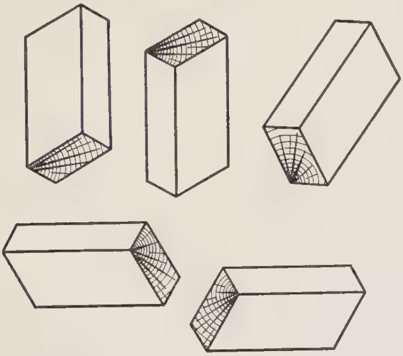

FIG. 36

The distinction between the two is a very fine one, since, if the ratio of foreshortening* be used as a scale to which the drawing is made, then it is possible by a simple statement, to change from isometric drawing to isometric projection. The commercial name will be followed and they will be called isometric drawings, always bearing in mind that the distinction means little.

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* This ratio of the actual dimension to the true projected dimension is 100 : 83 and may be computed by trigonometry.

404. Direction of axes. It is usual to assume one of the axes as either horizontal, or vertical, as under these circumstances, the other two can be drawn with the 60° triangles which are standard appliances in the drawing room. Fig. 36 shows a wood block in several positions, each of which is an isometric drawing; here, the location of the observer with respect to the block is at once apparent.

405. Isometric projection of circles. As no line is shown in its true length when it lies in the faces of the cube and is projected isometrically, then, also, no curve that lies in these faces can be shown in its true length and, therefore, in its true shape. This is due to the foreshortening caused by the inclination of the plane of the three principal dimensions to the plane of projection.

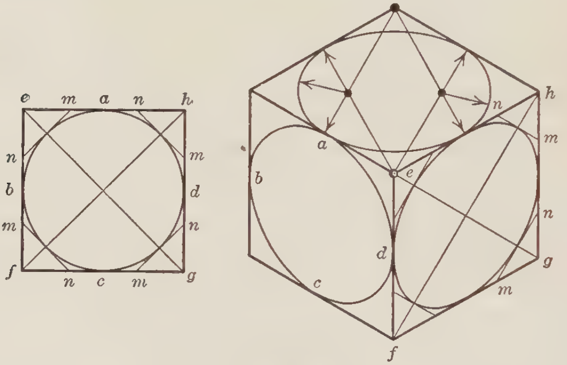

FIG. 37

Fig. 37 shows two cubes, the one on the left appears as a single square because it is an orthographic projection and this plane was parallel to the plane of projection. On the right, an isometric drawing is shown. In the orthographic projection on the left, a circle is inscribed in the face of the cube. The circle, so drawn, is tangent to the sides of the square at points midway between the extremities of the lines. When this square and its inscribed circle is shown isometrically, the points of tangency do not change, but, as the square is projected as a rhombus, the circle is projected as an ellipse, and is a smooth curve that is tangent at mid-points of the sides of the rhombus. A rapid, though approximate method of drawing an ellipse * is shown in the upper face of the isometric cube. The major and the minor axes of the ellipse can be laid off accurately by drawing the diagonals **eg** and **fh** (the notation being alike in both views); a tangent to the circle is perpendicular to the radius, and, for points on the diagonals, this tangent is shown as **mn** (all four are alike because they are equal). Showing **mn** isometrically means that the **gm** = **gn** in one view is equal to the **gm** = **gn** in the other view; the **hm** = **hn** in one view is equal to the **hm** = **hn** in the other view, and so on, for the four possible tangents at the diagonals.

406. Isometric projection of inclined lines and angles. Suppose it is desired to locate the centre of a hole in one of the faces of a cube as at **h** (Fig. 38). The hole is 12″ back from the point **f**, on the line **fm**, and 6″ up from the point **m**; **hfm** is the isometric representation of a right triangle whose legs are 6″ and 12″. It will be observed that none of the right angles of the cube are shown as such, therefore, the angle **hfm** is not the true angle corresponding to these dimensions; and, hence, it cannot be measured with a protractor in the ordinary way.

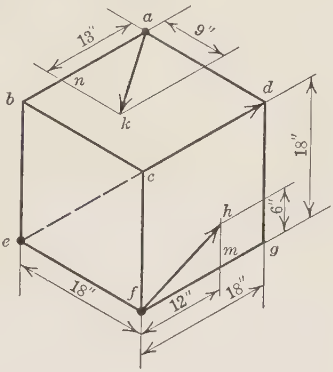

FIG. 38.

The point **k** is located in a similar manner on the top of the cube, while **ank** is the isometric drawing of a right triangle whose legs are 9″ and 13″. A diagonal **ed** of the cube is also shown.

The general method of drawing any line in space is to plot the three **components** of the line. For instance, the point **d** is located with respect to the point **e**, by first laying off **ef**, then **fg**, and finally **gd**.

407. Isometric graduation of a circle.† If the plane of a circle is parallel to the plane of projection, the projection is equal to the circle itself and, hence, it can be drawn with a compass to the required radius. Any angle is then shown in its true size and thus the protractor can be applied in its graduation.

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* The exact method of constructing an ellipse will be found in any textbook on geometry.

† This method is also applicable to oblique projection.

When circles are shown isometrically, however, their projections are ellipses, and the protractor graduation is applicable no longer. In the upper face of the cube, shown isometrically in Fig. 39, the circle is shown as an ellipse whose major and minor axes are respectively horizontal and vertical. If, on the major axis **ab**, a semicircle is drawn, and graduated by laying off angles at 30° intervals, the points **CDEF** and **G** are obtained making six angles at 30°, or a total of 180°, the angular measure of a semicircle. If, then, the plane of the circle is rotated about **ab** as an axis, until the point **E** coincides with **e**, each point of division on the semicircle will find itself on the similarly lettered point of the ellipse; because, then, the plane of the semicircle coincides with the plane of the upper face of the cube. Therefore, **aoc, cod, doe,** etc., are 30° angles, shown isometrically.

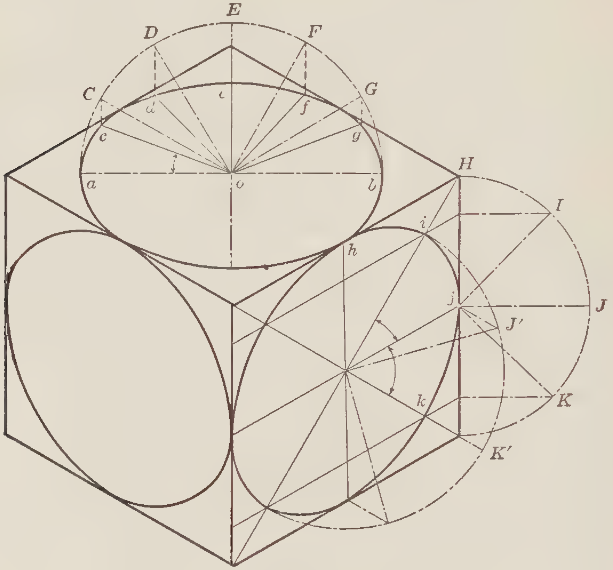

Fig. 39.

In the side face of the same cube are shown two methods of laying off 45° angles. The fact that both methods locate the

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same points tends to show that either method, alone, is applicable. The lettering is such that the construction should be clear without further explanation.

408. Examples of isometric drawing. As an example, the steps in the drawing of a wooden horse, shown in Fig. 40 and used in the building trades for supporting platforms and the like, will be followed. The making and the subsequent interpretation of drawings of this kind is facilitated by the introduction of bounding figures of simple shape. In the example chosen, the horse is bounded by a rectangular prism. The attached dimensions show the necessary slopes and may be introduced so as to replace the bounding figure. There is nothing new in this drawing and therefore the description will not be needlessly exhaustive. The bounding figure, when appended to a drawing like that of Fig. 40, helps to emphasize the slopes of the various lines. In general, the bounding figure should be removed on completion of the drawing.

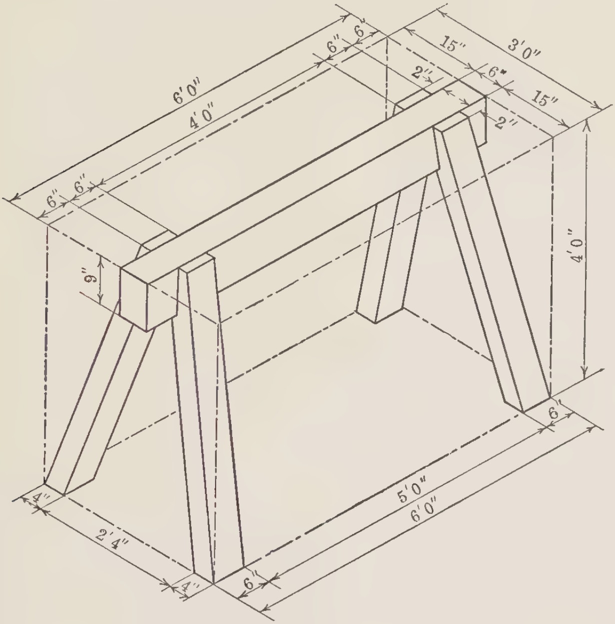

Fig. 40.

Fig. 41 shows a toothed wheel. The plane of the circles corresponds to the plane of the top face of a cube. To construct it, it is necessary to lay out the prism first and then to insert the ellipses. The graduation of the circle is similar to that indicated in Art. 407.

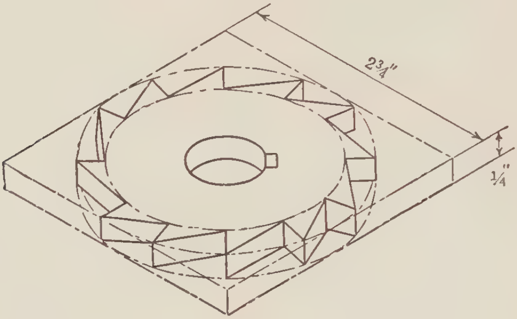

Fig. 41.

A lever is shown in Fig. 42. The centre line **ab** lies in the top face of the lever proper. Circumscribing prisms determine the ends of the lever and also the projecting cylindrical ends.

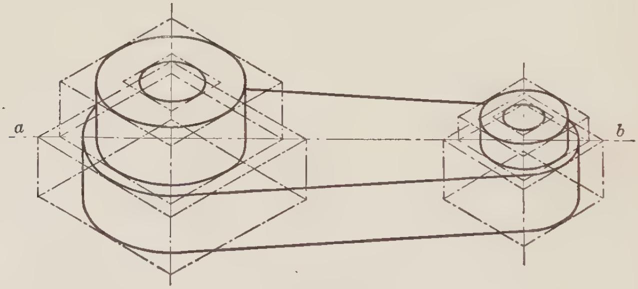

Fig. 42.

A gas-engine fly-wheel is illustrated in Fig. 43. Here the fly-wheel is shown so that the planes of the circles correspond to one of the side faces of a cube. The wheel has a solid web (without spokes) and a quarter of it is removed and shown in section.

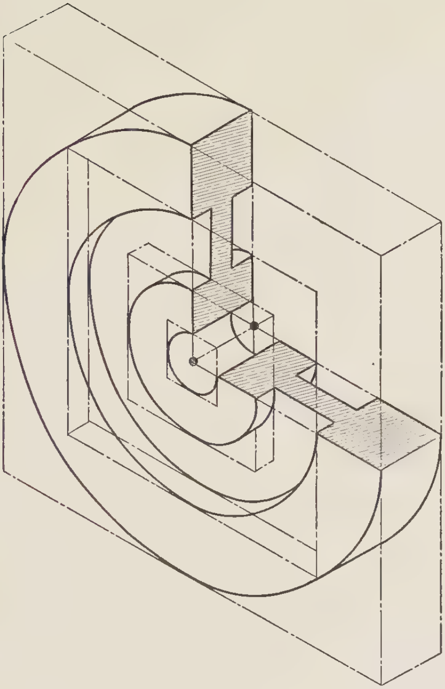

FIG. 43.

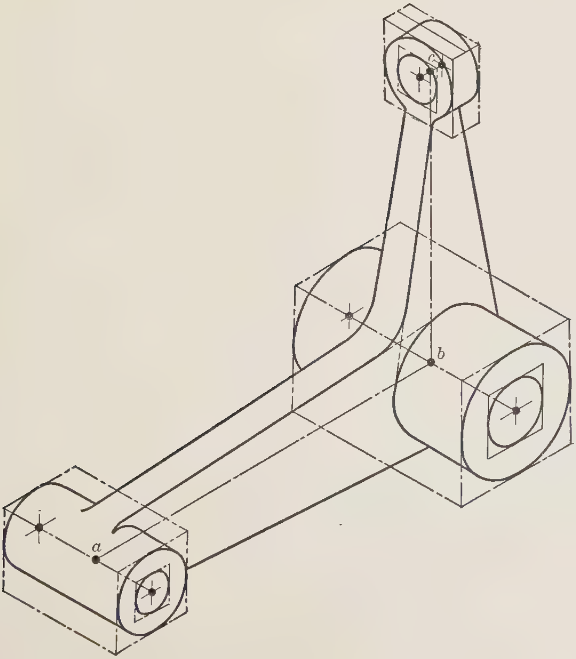

FIG. 44.

Fig. 44 represents a bell-crank. Again the scheme of using base-lines in connection with circumscribing prisms is shown. This view should be compared with that given in Fig. 17.

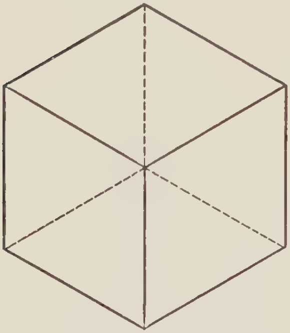

FIG. 45.

409. Dimetric projection and dimetric drawing. Let Fig. 45 be the isometric projection of a cube, with the invisible edges shown dotted. A disturbing symmetry of the lines is at once apparent. This objection becomes serious when applied to drawing if the objects are cubical, or nearly so.

The foregoing difficulty may be partially overcome by turning the cube so that only two faces are projected equally and the remaining face may be larger or smaller at pleasure. Fig. 46 shows this condition represented. The angle **aoc** is larger than either the angles **aob** or **cob**, the latter two (**aob** and **cob**) being equal. The faces **A** and **B** are projected equally, whereas **C** is smaller in this particular case, though it need not be. The illustration as shown on the right of Fig. 46 is a **dimetric projection** and, as such, the same scale is applied to the axes **oa** and

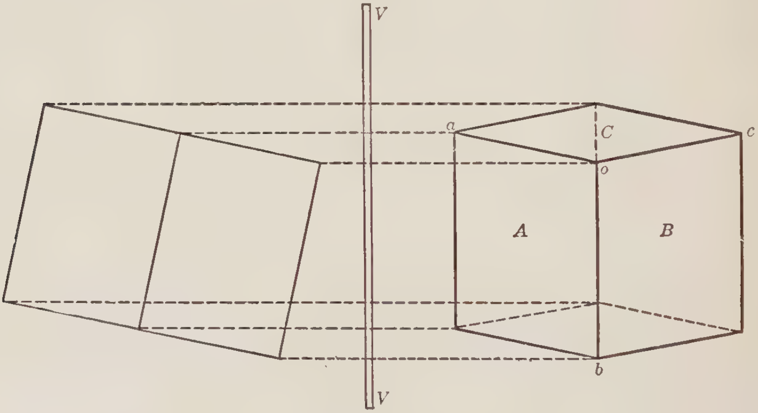

FIG. 46.

oc because they are projected equally. The axis **ob** is longer, since the corresponding edge is more nearly parallel to the plane of projection **VV** than either **oa** or **oc**. Hence, to be theoretically correct, a different scale must be used on the axis **ob**.

When dimetric projection is to be commercially applied, confusion may result from the use of two distinct scales. If one scale is used on all three axes the combination becomes a **dimetric drawing.** Hence, a dimetric drawing differs from an isometric drawing, in so far, as two of three angles are equal to each other for the dimetric drawing; whereas, in isometric drawing, all three are equal, that is, the axes are 120° apart.

What is true of the direction of the axes in isometric drawing is equally true here, that is, the angular relation between the axes, alone, determines the type of projection, the direction of any one is entirely arbitrary.

Dimetric drawings do not entirely remove the objectionable symmetry, yet they find some use in practice, although they present no distinct advantage over any other type.

410. Trimetric projection and trimetric drawing. Fig. 47 shows a cube which is held in such a position that the orthographic projection of it will result in the unequal projection of the three visible faces. This, then, becomes a **trimetric projection.**

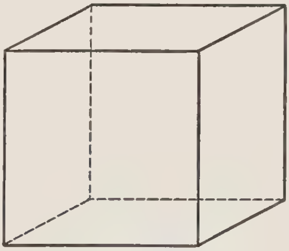

FIG. 47.

To make true projections, three different scales must be used. This, of course, is objectionable and, hence, recourse is had to a **trimetric drawing.** A trimetric drawing, therefore, requires three axes. The angles between the axes differ, but no one angle can be a right angle in any case.* The same scale is applied to all three. Also, the axes may have any direction, so long as attention is paid to the angular relation between them.

---

* This evidently makes it an oblique projection. It is impossible to project a cube orthographically to produce this; since, if two axes are parallel to the plane of projection, the third axis must be perpendicular and is hence projected as a point. The oblique projection of a cube, which is turned as it would be in isometric drawing, presents no new feature since it results, generally speaking, in a trimetric projection.

If isometric drawings introduce the disturbing symmetry, then the trimetric is to be recommended, unless one of the other types of drawing is found to be more suitable. No examples are given in this connection, because the application of dimetric and trimetric drawings involve no new features. It is only to be remembered, that artistic taste may dictate the direction of the axes, so as to present the best view of the object to be illustrated.

411. Axonometric projection and axonometric drawing. Isometric, dimetric, and trimetric projection form a group which may be conveniently styled as **axonometric projections.** All three are the result of the orthographic projection of a cube, so that the three principal axes are projected in a manner as already indicated. Axonometric projections are therefore a special case of orthographic projection, but their advantages are sufficiently prominent to warrant separate classification.

For isometric projection, one scale is used throughout; for dimetric projection, two separate scales are used; and for trimetric projection, three distinct scales are used. When applying axonometric projections to drawing, the same scale is used on all axes, and the group then represents a series which may be called **axonometric drawing.**

The distinction between isometric projection and isometric drawing has been pointed out (Art. 403). It becomes more prominent, however, in dimetric and trimetric projection.

412. Commercial application of axonometric projection. For objects of simple shape, with few curves, isometric drawings serve a useful purpose, because they are easily made and are easily read by those unfamiliar with drawing in general. When curves are frequent and it is desirable to picture objects in a single view, oblique projections offer advantages over isometric drawings because it may be possible to make the planes of the curves parallel to the plane of projection. The curves will then be projected as they actually appear. When curves appear in many planes, then orthographic projections will answer requirements best, but, as already mentioned, their reading is more difficult, due to the simultaneous interpretation of two or more views.

Before dismissal of the subject of projections in general, attention is called to Fig. 48 which is a peculiar application of isometric drawing. It is frequently used as an example of an optical illusion. By concentrating the vision at the centre of the picture, there seems to be a sudden change from six to seven cubes, or vice versa, depending upon whether the central corner be regarded as a projecting or a depressed corner. This is due to the fact that all of the cubes are shown of the same size, a condition which is contrary to our everyday experience. As objects recede from the eye, they appear smaller; and in isometric projection there is no correction for this. In fact, all the projections so far considered, draw on the imagination for their interpretation,* and, therefore, they cannot present a perfectly natural appearance.

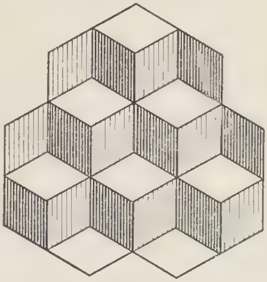

Fig. 48.

413. Classification of projections. All projections having parallel projecting lines may be classified according to the method by which they are made. This classification furnishes a useful survey of the entire subject and also serves to emphasize the distinction between the different methods.

It will be found, on analysis, that if the object be conceived in space with its parallel projecting lines, the oblique projections result when the plane of projection cuts the projecting lines obliquely. When the plane of projection cuts the projecting lines at a right angle, then the orthographic series of projections arise. If, still further, the projecting lines, coincide with some of the principal lines on the object, and the plane of projection is at right angles to the projecting lines, then the **two-dimension** orthographic projections result, and these are commonly called **mechanical drawings.** If the projecting lines do not coincide with some of the principal lines on the object, then the axonometric series of projections follow.

---

* The projections that overcome these objections are known as Perspective Projections. In these, the projecting lines converge to a point at which the observer is supposed to be located. Photographs are perspectives in a broad sense.

CLASSIFICATION OF PROJECTIONS HAVING PARALLEL PROJECTING LINES

PROJECTIONS

- On Plane Surfaces:
  - **Oblique.** Projecting lines inclined to plane of projection but parallel to each other.
    - Inclination of projecting lines 45° with plane of projection.
      - All lines projected equal in length. Hence, same scale used on all.
    - Inclination of projecting lines greater than 45° with plane of projection.
      - Lines parallel to plane of projection drawn to equal length. Lines perpendicular to plane, projected as shorter lines to diminish distortion.
  - **Orthographic.** Projecting lines perpendicular to the plane of projection.
    - **Mechanical Drawing.** showing two principal dimensions on a single view. Hence, at least two views needed
      - Principal lines of object parallel or perpendicular to planes of projection. Sometimes called **Orthographic projection.**
    - **Axonometric.** projection, showing three dimensions in a single view.
      - **Isometric.** All three axes of cube projected equally, hence, axes are 120° apart and equal in length. Applied as **Isometric Drawing.**
      - **Dimetric.** Two of the three axes projected equally, hence, only two angles equal. Applied as **Dimetric Drawing.**
      - **Trimetric.** Axes projected unequally, hence, all three angles differ. Applied as **Trimetric Drawing.**
- On **Curved** Surfaces:
  - Not used in Engineering drawing.

QUESTIONS ON CHAPTER IV

1. What are the isometric axes?
2. How are they obtained?
3. What is the angular relation between the pairs of axes?
4. Show why the isometric projection is a special case of orthographic.
5. What is the distinction between isometric projection and isometric drawing?
6. What direction do the axes have for their convenient application to drawing?
7. How is a circle projected isometrically?
8. Show the approximate method of drawing the isometric circle.
9. How are inclined lines laid off isometrically?
10. How are angles laid off isometrically?
11. Show that the laying off of an inclined line is accomplished by laying off the components of the line.
12. How is the isometric circle graduated in the top face of the cube?
13. Show how the graduation is accomplished in one of the side faces of the cube.
14. What is a dimetric projection?
15. What is a dimetric drawing?
16. What angular relation exists between the axes of a dimetric projection?
17. What is a trimetric projection?
18. What is a trimetric drawing?
19. What angular relation exists between the axes of a trimetric drawing?
20. Show why the trimetric drawing eliminates the disturbing symmetry of an isometric drawing.
21. Why cannot the angle between one pair of axes be a right angle?
22. What are axonometric projections?
23. Why do projections with parallel projecting lines draw on the imagination for their interpretation?
24. Draw the object of Question 33 in Chapter 2 in isometric drawing. Use bounding figure.
25. Draw a triangular prism in isometric drawing. Use a bounding figure.
26. Make an isometric drawing of a hexagonal prism. Use a bounding figure.
27. Make an isometric drawing of a hexagonal pyramid. Use a bounding figure.
28. Make an isometric drawing of 3–A (Question in Chapter 3).
29. Make an isometric drawing of 3–B.
30. Make an isometric drawing of 3–C.
31. Make an isometric drawing of 3–D.
32. Make an isometric drawing of 3–F.
33. Make an isometric drawing of 3–G.
34. Make an isometric drawing of 3–H.

35. Make an isometric drawing of 3–I.
36. Make an isometric drawing of 3–J.
37. Make an isometric drawing of 3–K.
38. Make an isometric drawing of 3–L.
39. Make a complete classification of all projections having parallel projecting lines.

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